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NATIONAL BUREAU OF STANDARDS REPORT

10 475

STUDY OF FIRE DEVELOPMENT IN A ROOM

Summary Data Report No. 2

July 1971

NBS

U.S. DEPARTMENT OF COMMERCE

NATIONAL BUREAU OF STANDARDS

NATIONAL BUREAU OF STANDARDS

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STUDY OF FIRE DEVELOPMENT IN A ROOM

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by
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Fire Research Section
Building Research Division
Institute for Applied Technology
National Bureau of Standards

Prepared for
U. S. Department of Housing and Urban Development
and
U. S. Army Natick Laboratories

IMPORTANT NOTICE

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ABSTRACT

The energy release characteristics of burning wastebaskets filled with various types of combustibles are summarized. Steel and polyethylene wastebaskets ranging from 5 to 32 gallon capacity were filled with paper tissues, towels, and wrapping paper or waxed milk cartons. Results are presented in terms of rate of fuel consumption, temperature, and radiation and total heat flux levels at several locations near the wastebasket. The maximum heat flux from the flame to a surface tangent to the wastebasket rim ranges from 0.6 to 5.3 W/cm^2.

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1.0 INTRODUCTION

The potential fire risk or damage to contents or structures in buildings depends upon the intensity and duration of the exposing fire, the environmental temperature and the physical and thermal properties of the exposed combustible material and its distance from the fire. This part of the program is attempting to define "minor fires", the type of exposing fire which occurs in wastepaper baskets or trash cans.

The present program in its early stages is primarily concerned with a determination of the level of heat flux transferred from typical minor fires to the surroundings; and with an evaluation of the factors affecting the rate and duration of burning of various combustible contents in trash containers. This report is supplemental to a previous one reporting on an experimental study of the burning characteristics of wastebasket fires containing various amounts of combustibles. This report presents some additional test results on a study of the influence of the size and type of containers and type of fuel on the burning rate and heat transfer phenomena.

2.0 TEST EQUIPMENT

Experiments were performed in a new fire test room of 9-1/2 feet by 10-1/2 feet dimensions and 8 feet high. One door 4 feet 2 inches by 7 feet 9 inches high was located in one of the smaller compartment walls. The whole test compartment was situated inside a large test building. The compartment walls and ceiling were concrete (except one wall was 5/8 inch gypsum wallboard on steel studs) and all exposed interior surfaces were sprayed with an insulating vermiculite/gypsum plaster.

Four copper disc calorimeters were constructed and mounted in an asbestos board holder, which was placed along the edge of the container to measure the maximum rates of total heat flux in direct contact with the flame during the test. The 1 inch diameter by 1/8 inch thick discs had a

blackened front surface and a thermocouple attached at its center. The rate of temperature rise is directly related to the incident heat flux. Three additional bare-headed chromel-alumel thermocouples were separately fixed firmly to the top, mid-height and bottom of the outside lateral wall of the wastebasket for measuring its surface temperatures during the fire.

Six types of galvanized or painted steel trash baskets were used, five were of round cross-section, one was square.

The rest of the apparatus employed for these tests was the same as previously described in the first report. All of the thermocouples and radiometers were connected to a data logger which printed the temperatures and mv outputs at each location at one minute intervals. A twelve channel temperature recorder was also used for recording the average temperatures of each copper disc or copper pan calorimeter at seven second intervals. Figures 1 and 2 show details of the instrumentation in the test compartment.

3.0 TEST PROCEDURE

The same test procedure was used for these tests as described previously in the previous report. For all tests, the trash container without cover was filled with preweighed combustible materials to maximum load conditions. This condition might occur in an office or residence; and could be a likely cause of a fire.

The materials were ignited by a flaming propane torch applied momentarily.

4.0 EXPERIMENTAL RESULTS

A series of 29 tests was conducted, using several combustibles such as waxed milk cartons, paper tissue, carbon paper, paper towels, and Kraft wrapping paper. Table 1 summarizes the variables utilized for each test.

The repeatability of the tests was re-examined by performing three experiments under the same conditions (Test Nos. 35, 43, and 44). In addition a separate test was run to duplicate one experiment described in the preliminary report.

Figures 3 and 4 present these results graphically showing the test fires having a fairly reproducible rate of burning. The figures also indicate that the combustibles burned at a considerably faster rate at the early stage of fires and then tended to decrease as the fire spread downward into the wastebasket. Apparently as fire burns inside the container, the fuel consumption rate is limited by the rate of air supply to the reaction zone. A condition of ventilation-controlled combustion prevails during this period. of the fire. In addition, buoyant force produced by rising fuel volatiles and the friction effect due to gradual accumulation of ashes have a pronounced influence on air inflow.

The consumption rate of the burning combustibles and the peak temperatures of hot gases both within the flame plume and 1 inch below the compartment ceiling

are tabulated and presented in Table 2. The measured maximum plume temperature varied from 700° to 1050°C with an average of approximately 860°C. The temperature of air at the vicinity of the compartment ceiling generally ranged from 100° to 400°C at the peak of fires for all tests.

A preliminary study was made to determine the influence of container size on the fuel burning rate. The results of the series of tests in which fuel bed void fraction was maintained approximately constant for waxed milk cartons and Kraft paper towels are shown in Figures 5 and 6 where the rate of burning is plotted against the capacity and inside diameter of the container respectively. The data indicate that the rate of fuel consumption increases with an increase in container's capacity or inside diameter.

For most fires in the open, as the size of the fuel source increases the overhead flame tends to be a large fully turbulent and optically thick blackbody emitter. This is attributed to a significant increase in the emissivity and temperature of the flame due to increasing flame size. The dominant heat transfer to the fuel, which controls the burning rate, passes from conduction and convection mechanisms to radiation process. For large diameter fires, this condition is more apparent. Thus, it might be expected that increasing the container diameter would produce a higher burning zone temperature and rate of feedback heat from the flame to the fuel, resulting in more vigorous combustion.

The effect of fire load density on the average burning rate, expressed in percent/min., is shown in Figure 7. This graph includes data from tests with small wastebaskets reported previously. The average relation for all steel wastebasket test data can be represented by RD=5, where R=rate of burning, percent/min and D=fire load density, g/cm^2.

The results of maximum incident heat flux measured at the proximity of the flame through direct flame contact and at various distances from the container centerline (4 inches above its edge) at the peak of fire are presented in Table 3.

The accuracy of the transient technique used for measuring the instaneous surface heat flux acting on the copper disc from the flame depends on the extent of agreement with the condition that temperature difference across the thickness of the disc is negligible or the thermal conductivity of disc is infinitely large. The copper employed for the disc calorimeters have a high conductivity, in such case the measured values for all tests may be slightly lower than the actual ones.

Using the copper disc calorimeters, the maximum total heat transfer from the flame to a surface tangent to the rim of the container varied from 0.6 to 5.3 W/cm^2 with an average of about 2.3 w/cm^2. This heat transfer rate from flame gas to solid surface through both convection and radiation. is quite capable of producing the ignition of adjacent cellulosic materials. The peak flux measured was at a height of 9 inches above the wastebasket and occurred about 2 minutes after ignition for most tests. The peak heat flux levels were maintained for 1 to 3 minutes.

The data for total flux at various locations were obtained from the radiometers, whose sapphire windows were removed, mounted on the stands and placed parallel to the wastebasket centerline at an elevation of 4 inches above the top edge of the container. It can be noted that at a short distance of 2 to 6 inches away from the wastebasket, radiation became the dominant mode of energy transport as the radiative component comprised approximately 70 percent of the total energy. The flux distribution is shown graphically in Figure 8.

Table 4 summarizes the maximum rate of heat transmitted downward to the floor underneath the container, the maximum radiant flux emitted and peak temperature attained by the container wall during each test. The plastic container usually reached a higher temperature, ranging from 600° to $800^\circ C$ at its lateral surface, whereas the measured temperature for a metal container varied from 160° to $500^\circ C$.

Figure 9 shows the effect of the type of container on the maximum downward heat flux and the fuel burning rate, for two types of combustible contents. The data indicate that the heat flux conducted to the floor and the rate of burning combustible inside a plastic wastebasket is significantly higher than that from a fire in a metal container. These results are expected since a considerable amount of heat was liberated from the burning of the plastic container itself.

A plot of the maximum incident heat flux at a point 9 inches above the container rim versus fuel burning rate is shown in Figure 10. It is evident that the magnitude of peak heat flux close to the flame plume is generally proportional to the rate of fuel consumption. (For the waxed milk cartons, the range in measured fuel consumption rate was very limited.) An increase in fuel burning rate would undoubtedly produce an increase in the flow of hot gases past the adjacent surface, thereby yielding a higher rate of heat transfer to the surface through forced convection. The figure also shows that the waxed milk cartons gave the highest incident flux values and the Kimwipe paper tissue had the least.

A mathematical analysis of free-burning fires in a wastebasket is in progress in hopes of correlating with the experimental results from these tests.

5.0 SUMMARY

Good repeatability has been obtained in the rate of burning of the contents of small and large wastebaskets.

A general relationship has been found to hold for the burning of the combustible contents of small and large metal wastebaskets. The average burning rate decreases with increasing fire load density according to the hyperbolic relation $R=\frac{5}{D}$, where R=rate of burning, percent/min. and D=fire load density, G/cm^2.

The maximum heat flux from the flame to a surface tangent to the wastebasket rim was found to range from 0.6 to 5.3 W/cm^2. The peak flux occurred at a height of about 9 inches above the rim, and its magnitude was generally proportional to the fuel burning rate. Close to the wastebasket, radiation accounted for approximately 70 percent of the total energy flux.

Plastic (polyethylene) wastebaskets produced higher rates of burning, higher basket wall temperatures and higher heat flux levels to the floor than metal wastebaskets.

TABLE I

Description of Tests

Test No.	Wastebasket Type	Wastebasket Size (in)	Wastebasket Capacity (gallons)	Combustible Load Type	Combustible Load Weight (g)	Fire Load Density (g/cm^2)
18	Steel	15-13 I.D. x 28 1/4	18.9	Kimwipes Paper Tissue	1367	1.60
19	Steel	15-13 I.D. x 28 1/4	18.9	Kimwipes Paper Tissue	1304	1.52
20	Steel	15-13 I.D. x 28 1/4	18.9	Kraft Wrapping Paper	2568	3.00
21	Steel	11 3/4 - 10 1/2 sq.x 14	7.04	Kraft Wrapping Paper	1157	1.63
22	Steel	11 3/4 - 10 1/2 sq.x 14	7.04	Waxed Milk Cartons	723	1.02
23	Steel	15-13 I.D. x 28 1/4	18.9	Waxed Milk Cartons	1663	1.94
24	Steel	14-12 1/2 I.D. x 16 1/2	9.86	Waxed Milk Cartons	907	1.15
25	Steel	12-10 1/2 I.D. x 11	4.74	Waxed Milk Cartons	595	1.07
26	Steel	17 1/2-14 3/4 I.D.x 23	20.4	Waxed Milk Cartons	1778	1.61
27	Steel	20-18 I.D. x 25	30.7	Kraft Paper Towel	1285	0.783
28	Steel	17 1/2- 14 3/4 I.D.x23	20.4	Kraft Paper Towel	853	0.774
29	Steel	15-13 I.D. x 28 1/4	18.9	Kraft Paper Towel	1090	1.27
30	Steel	14-12 1/2 I.D.x 16 1/2	9.86	Kraft Wrapping Paper	1469	1.86
31	Steel	14-12 1/2 I.D.x 16 1/2	9.86	Kraft Paper Towel	574	0.725
32	Steel	12-10 1/2 I.D.x 11	4.74	Kraft Paper Towel	200	0.358
33	Steel	20-18 I.D. x 25	30.7	Kraft Wrapping Paper	3490	2.13
34	Polyethylene	20-17 1/2 I.D.x 26 1/2	31.7	Waxed Milk Cartons	2799	1.80
35	Steel	20-18 I.D. x 25	30.7	Waxed Milk Cartons	2822	1.72
36	Polyethylene	20-17 1/2 I.D.x 26 1/2	31.7	Carbon Paper with Onion Skin	865	0.557
37	Steel	20-18 I.D. x 25	30.7	Carbon Paper with Onion Skin	865	0.527
38	Steel	11 3/4-10 1/2 sq.x 14	7.04	Kraft Wrapping Paper	619	0.870
39	Steel	20-18 I.D. x 25	30.7	Kimwipes Paper Tissue	1702	1.04
40	Steel	15-13 I.D. x 28 1/4	18.9	Kraft Paper Towel	790	0.923
41	Polyethylene	20-17 1/2 I.D.x 26 1/2	31.7	Kimwipes Paper Tissue	1718	1.11
42	Polyethylene	20-17 1/2 I.D.x 26 1/2	31.7	Waxed Milk Cartons	2794	1.80
43	Steel	20-18 I.D. x 25	30.7	Waxed Milk Cartons	2749	1.67
44	Steel	20-18 I.D. x 25	30.7	Waxed Milk Cartons	2780	1.69
45	Steel	17 1/2-14 3/4 I.D.x 23	20.4	Waxed Milk Cartons	1795	1.63
46	Steel	15-13 I.D. x 28 1/4	18.9	Kraft Paper Towel	790	0.923

TABLE 2 BURNING CHARACTERISTICS OF TEST FIRES

Test Number	Time Duration (min)	Fuel Burning Rate (g/min) Maximum	Fuel Burning Rate (g/min) Average	Maximum Temp (°C) Plume	Maximum Temp (°C) Compartment Ceiling
18	24.5	82.1	52.2	805	131
19	17.4	63.6	46.9	705	132
20	26.0	277.2	68.4	996	296
21	15.2	242.1	56.4	1001	184
22	12.5	161.3	48.4	886	190
23	23.2	192.0	48.1	1015	295
24	15.2	172.8	48.6	861	192
25	13.5	140.4	28.1	819	175
26	21.2	307.5	77.9	936	242
27	16.9	238.0	87.6	831	310
28	13.0	216.0	62.2	743	140
29	19.8	236.0	23.6	827	167
30	18.6	308.0	26.2	896	226
31	18.2	167.8	23.6	787	162
32	5.7	105.0	30.5	714	108
33	20.6	631.3	169.2	986	301
34	9.3	570.0	330.0	966	366
35	26.6	390.0	87.0	1059	341
36	17.4	393.0	236.0	818	270
37	4.9	258.7	155.2	781	247
38	15.7	144.0	57.6	703	110
39	16.0	265.2	145.9	808	133
40	26.0	166.0	41.5	797	122
41	22.0			894	163
42	16.1	584.8	481.6	934	395
43	25.3	420.0	90.0	855	302
44	27.6	465.1	94.7	844	324
45	24.6	277.5	66.6	860	254
46	20.1	166.0	39.4	819	142

TABLE 3

MAXIMUM TOTAL AND RADIANT HEAT FLUXES MEASURED AT VARIOUS LOCATIONS

Test No.	Time (Min)	Max. Incident Flux (W/cm^2)	Distance From The Fire Centerline: 1 FT		1 1/3 FT		1 1/2 FT		2 FT	3 FT
			Max. Tot. Flux (W/cm^2)	Irradiance (W/cm^2)	Max. Tot. Flux (W/cm^2)	Irradiance (W/cm^2)	Max. Tot. Flux (W/cm^2)	Irradiance (W/cm^2)	Max. Tot. Flux (W/cm^2)	Max. Tot. Flux (W/cm^2)
18	3.8	0.67	0.37				0.13		0.10	0.04
19	1.6	0.58	0.42				0.16		0.10	0.06
20	4.2	2.99	1.73	1.21			0.72		0.49	0.27
21	3.0	3.83	1.33	0.97			0.39		0.34	0.19
22	2.2	2.46	1.11	0.70			0.40		0.26	0.17
23	3.5	1.92	1.30	0.93			0.57		0.33	0.21
24	3.0	4.97	0.92	0.59			0.42		0.26	0.18
25	3.0	4.19	0.87	0.73			0.42		0.24	0.16
26	3.3	2.25	1.26	0.87			0.83		0.56	0.31
27	1.0	1.35	0.87	0.68			0.40		0.24	0.15
28	0.2	1.04	1.04	0.72			0.35		0.22	0.12
29	0.3	2.63	0.55	0.27			0.37		0.19	0.13
30	3.3	3.62	1.00	0.71			0.51		0.37	0.19
31	0.3	1.62	0.56	0.39			0.27		0.08	0.06
32	0.1	1.13	0.74	0.47			0.39		0.23	0.12
33	2.0	3.18			0.83	0.67	0.65		0.50	0.29
34	6.0	2.57					1.31	1.03	1.00	0.49
35	3.0	3.09			1.83	1.34	1.15		0.66	0.36
36	0.3	1.31					0.79	0.55	0.26	0.19
37	0.3	1.08			0.88	0.57	0.43		0.22	0.11
38	4.2	2.15	0.67	0.47			0.28		0.13	0.07
39	0.1	0.84			0.74	0.52	0.39		0.21	0.12
40	0.1	0.75	0.44	0.31			0.23		0.14	0.10
41	0.1	1.41					0.51	0.40	0.32	0.12
42	4.3	3.83					1.02	0.97	0.85	0.37
43	3.0	2.29			1.44	1.01	1.13		0.64	0.29
44	4.3	5.26			1.40	0.98	0.87		0.73	0.29
45	3.0	3.10	1.33	1.05			0.75		0.51	0.23
46	3.1	1.53	0.20	0.14			0.12		0.06	0.05

TABLE 4 MAXIMUM DOWNWARD HEAT FLUX, PEAK TEMPERATURE, AND IRRADIANCE AT THE CONTAINER

Test No.	Maximum Downward Flux	Wastebasket		
		Radiation		Container Wall Temperature (°C)
		Distance (Ft)	Max. Irradiance (W/cm^2)	
18	.2088			
19	.0140			
20	.0426			367
21	.2290			371
22	.4746			346
23	.0791			444
24	.1586			657
25	.2197			290
26	.2014	0.5	0.77	509
27	.1831	0.25	0.19	418
28	.1454	0.25	0.49	346
29		0.25	0.15	314
30	.0136	0.25	0.34	254
31	.0458	0.25	0.22	227
32	.0305	0.25	0.09	263
33	.1395	0.33	1.18	449
34	.9414	1.0	0.95	640
35	.4881	0.5	1.36	441
36	.7181	0.67	0.27	633
37	.4092	0.25	0.34	284
38	.0549	0.58	0.29	160
39	.2654	0.29	0.12	332
40	.1126	0.5	0.24	289
41	.2308	0.58	1.78	673
42	.5753	0.67	3.07	808
43	.3661	0.25	1.43	326
44	.3661	0.25	0.11	365
45	.4410	0.25	0.25	484
46	.1615	0.5	0.03	194

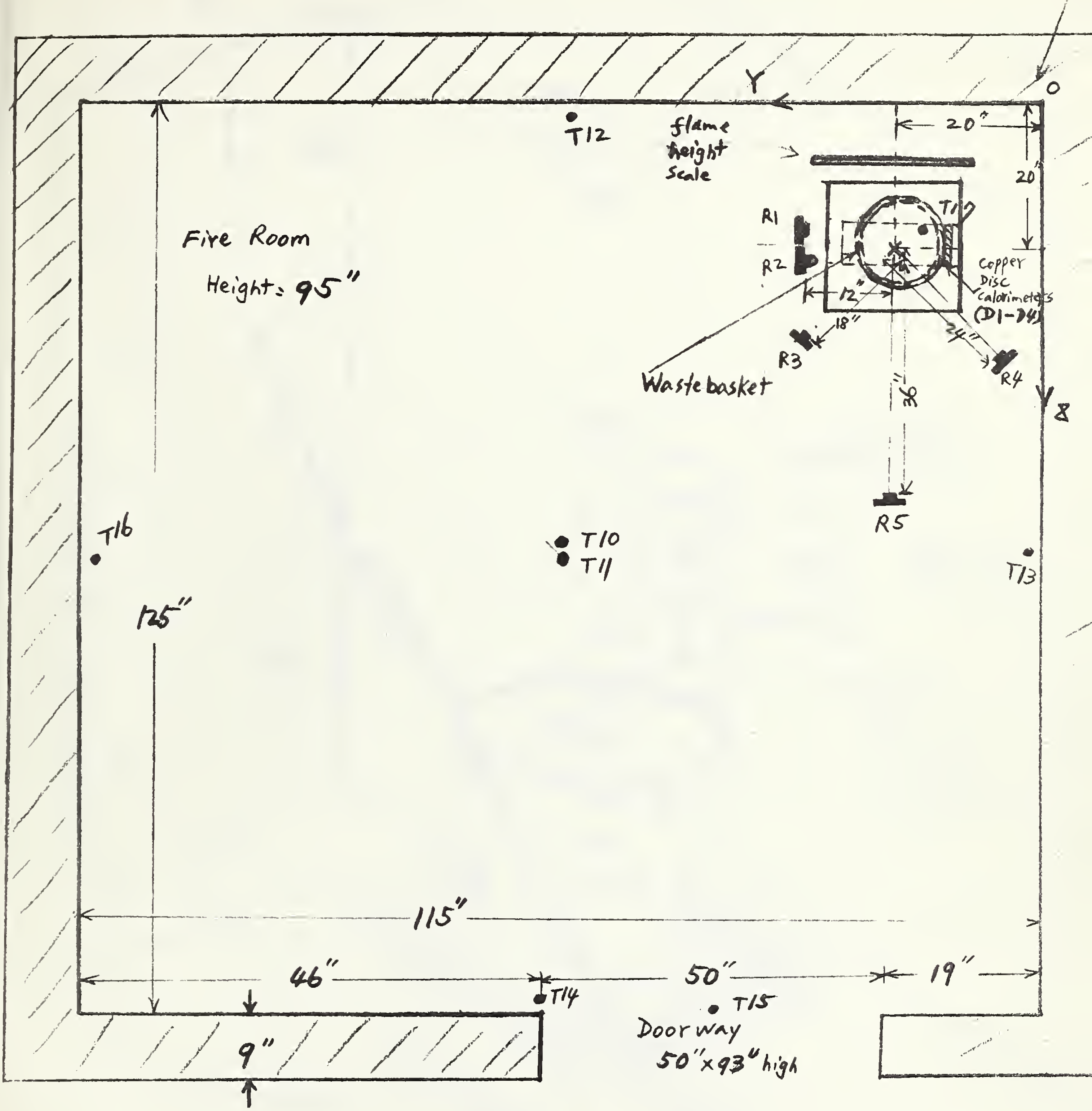


Figure 1 plan showing the locations of Thermocouples and Radiometers

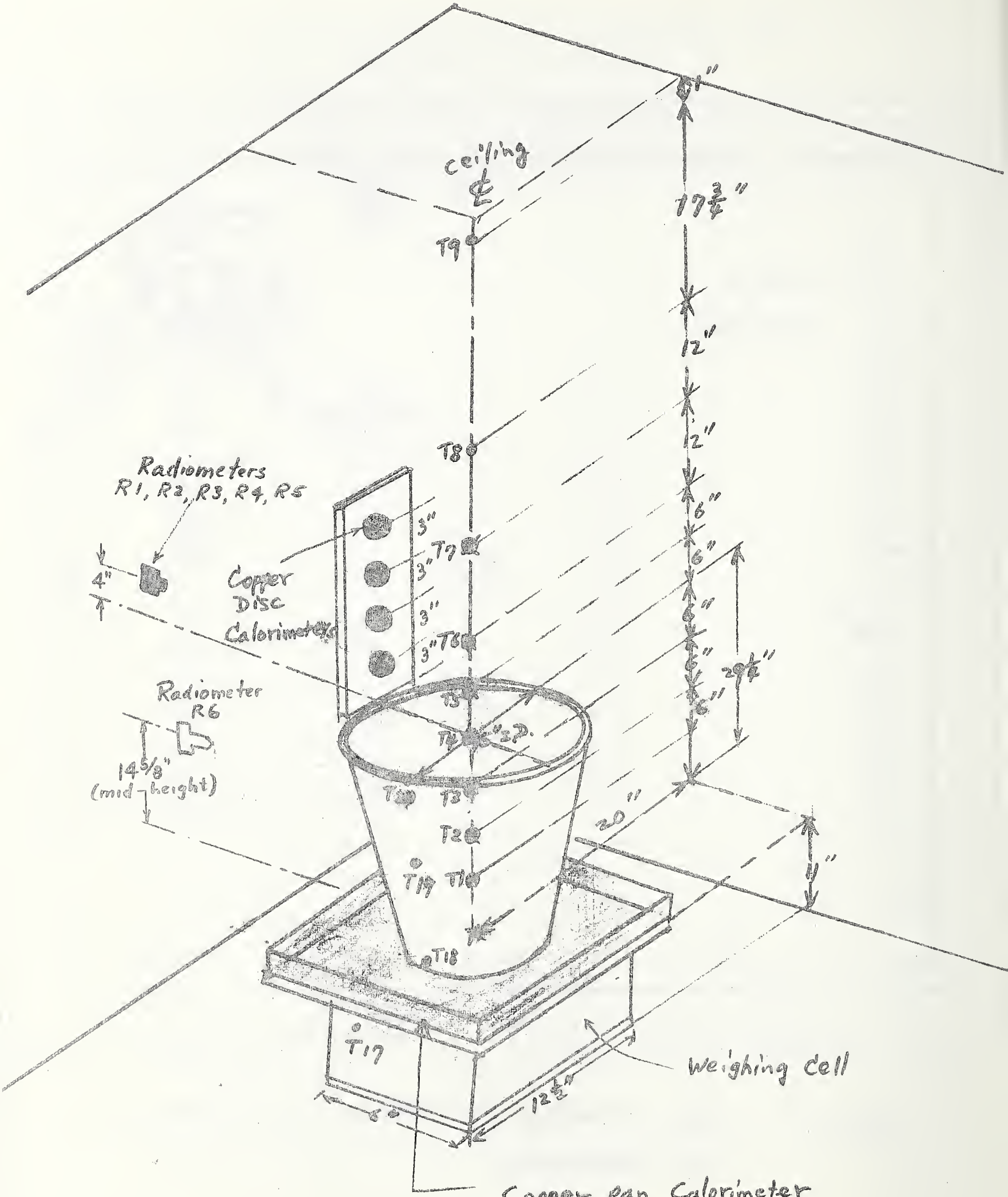


Figure 2 Elevation Indicating the Arrangements of Copper Disc and pan calorimeters, Load Cell and Thermocouples

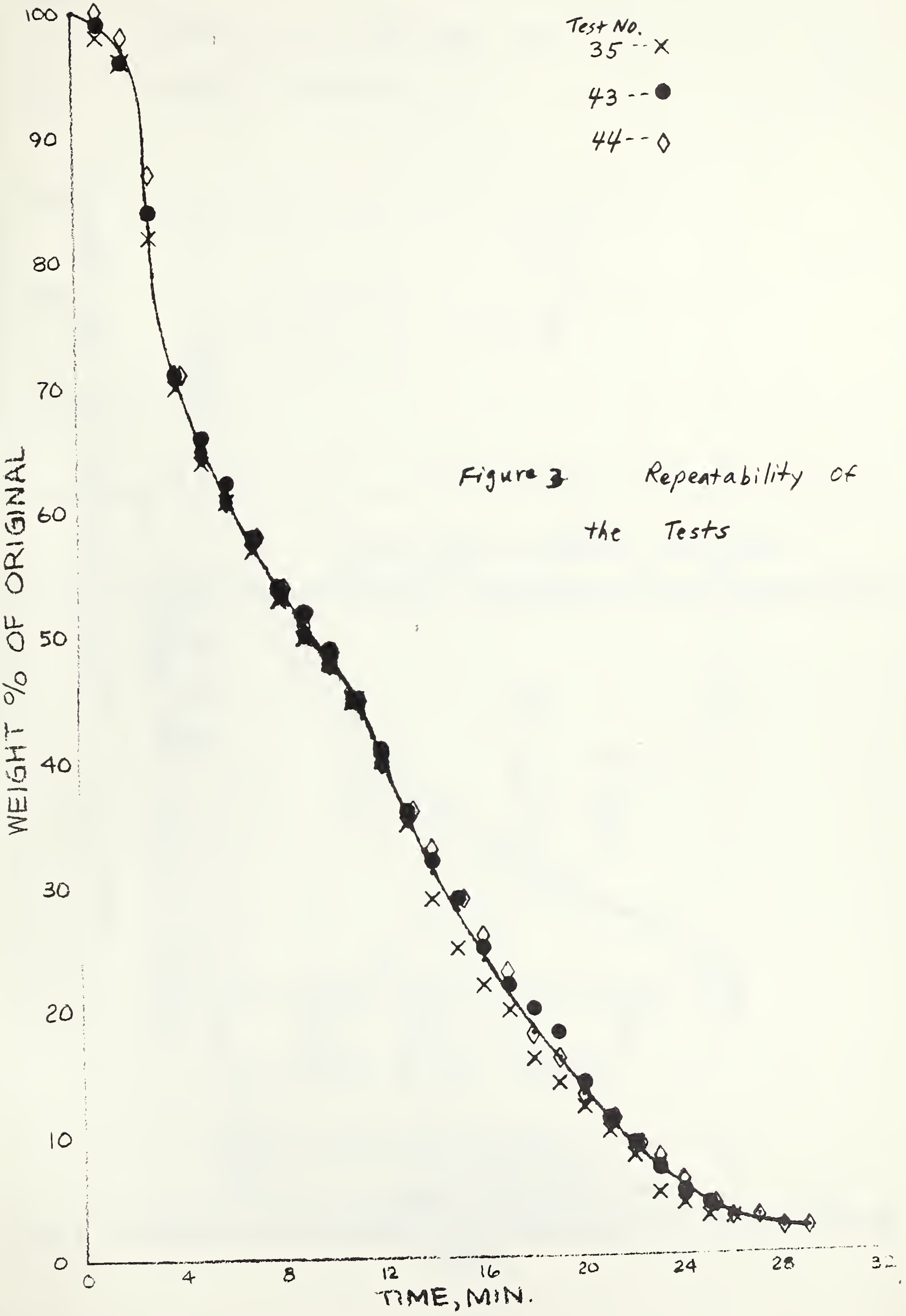


Figure 3 Repeatability of the Tests

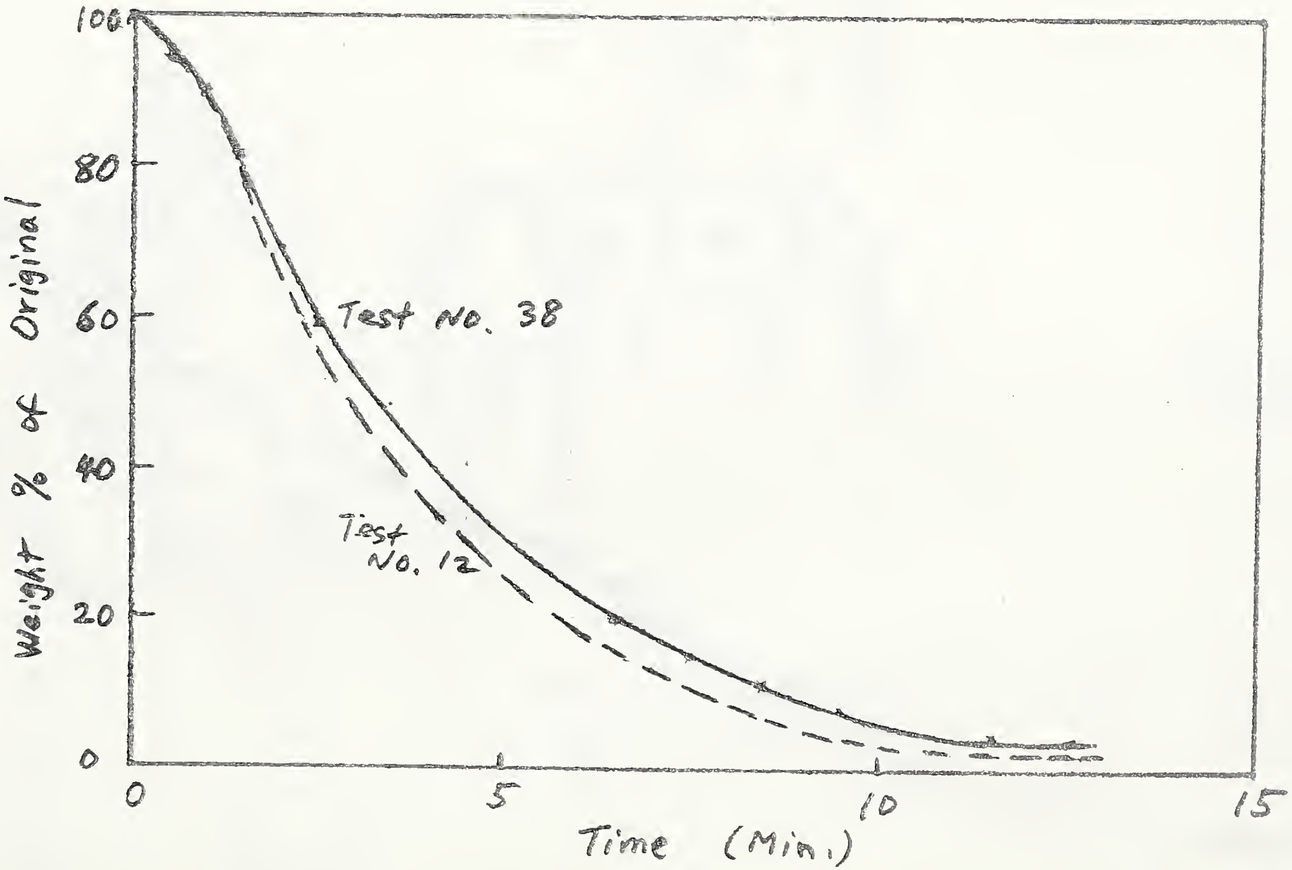


Figure 4 Reproduceability of the Results

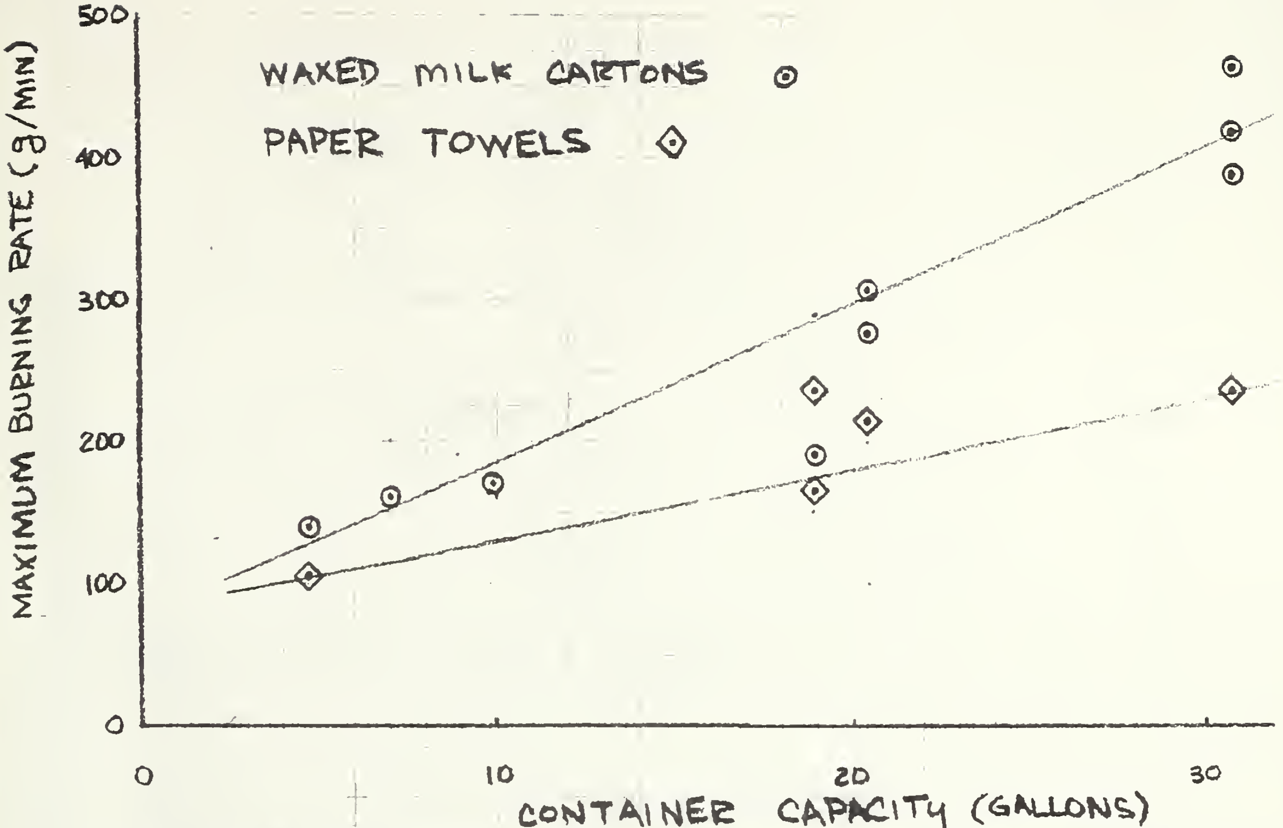


FIG. 5 EFFECT OF CAPACITY OF CONTAINER ON FUEL BURNING RATE

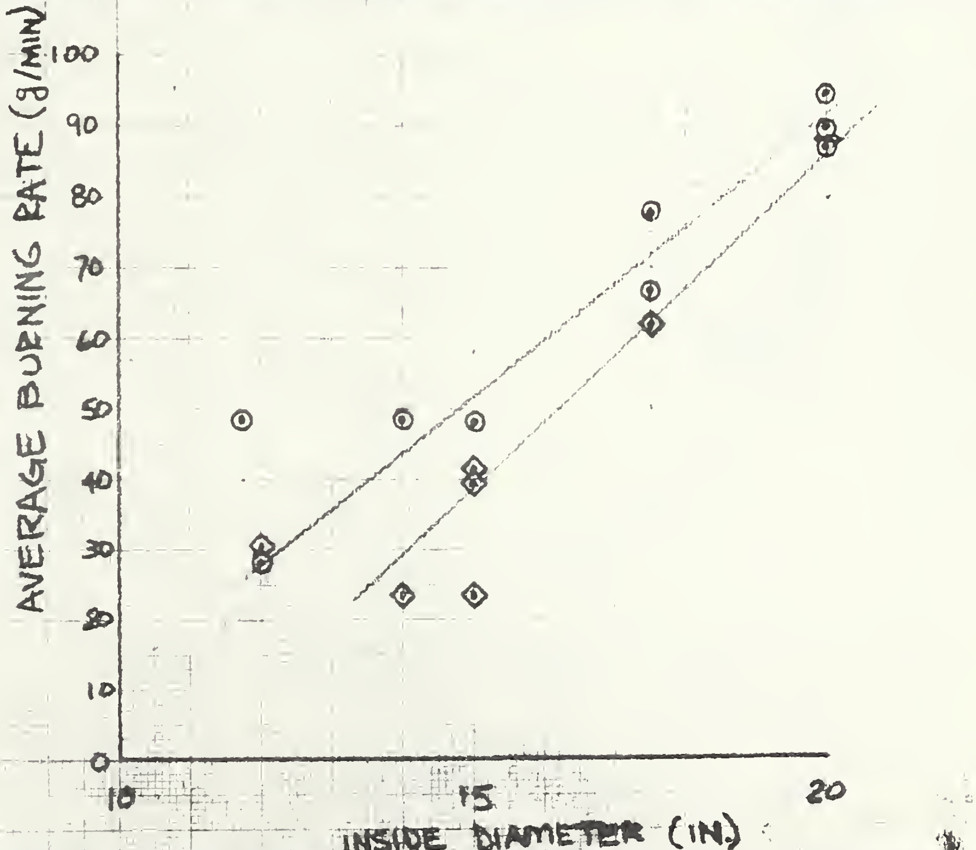


FIG. 6 EFFECT OF DIAMETER OF CONTAINER ON FUEL BURNING RATE

Fig. 7 EFFECT OF FIRE LOAD DENSITY ON BURNING RATE

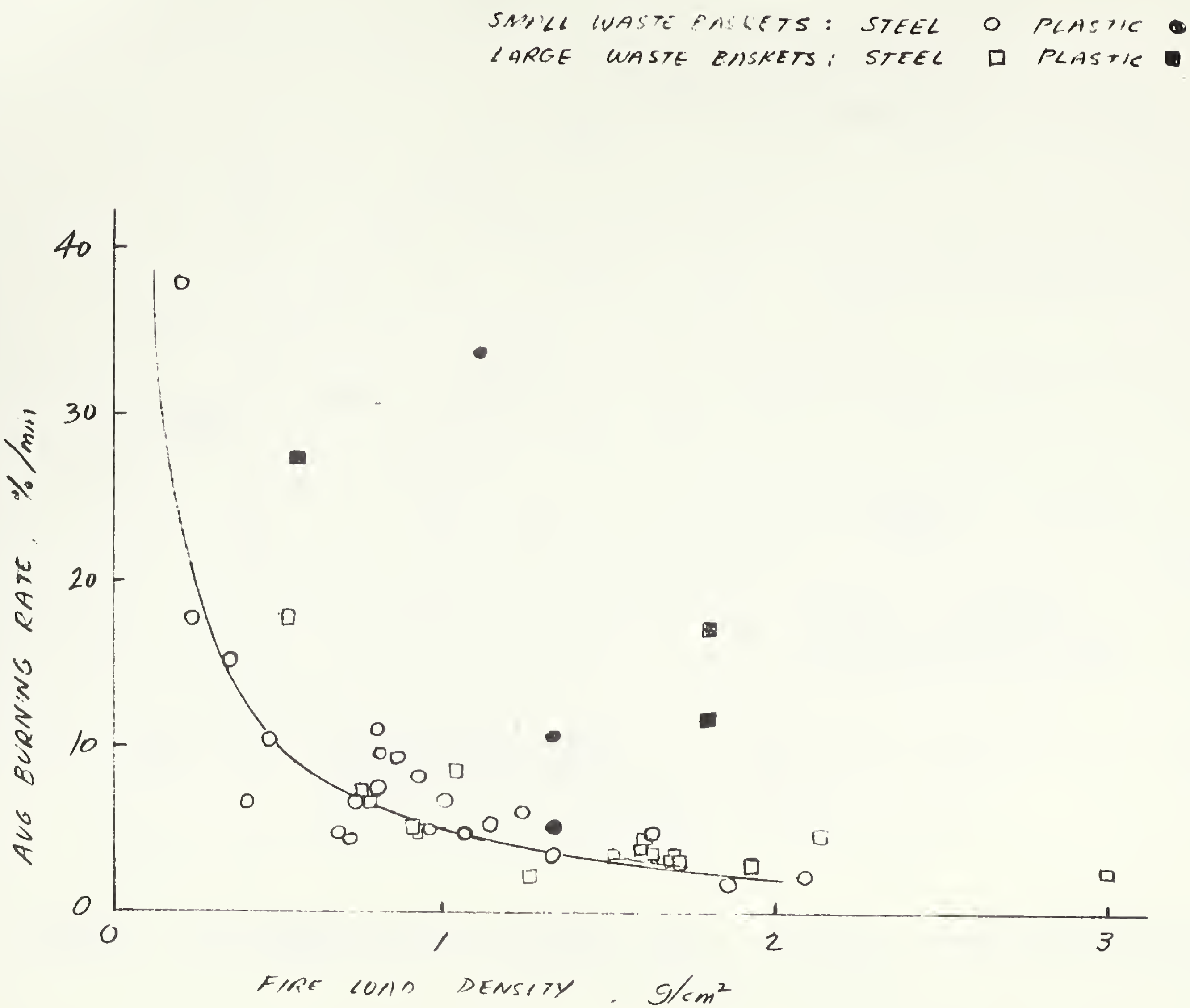
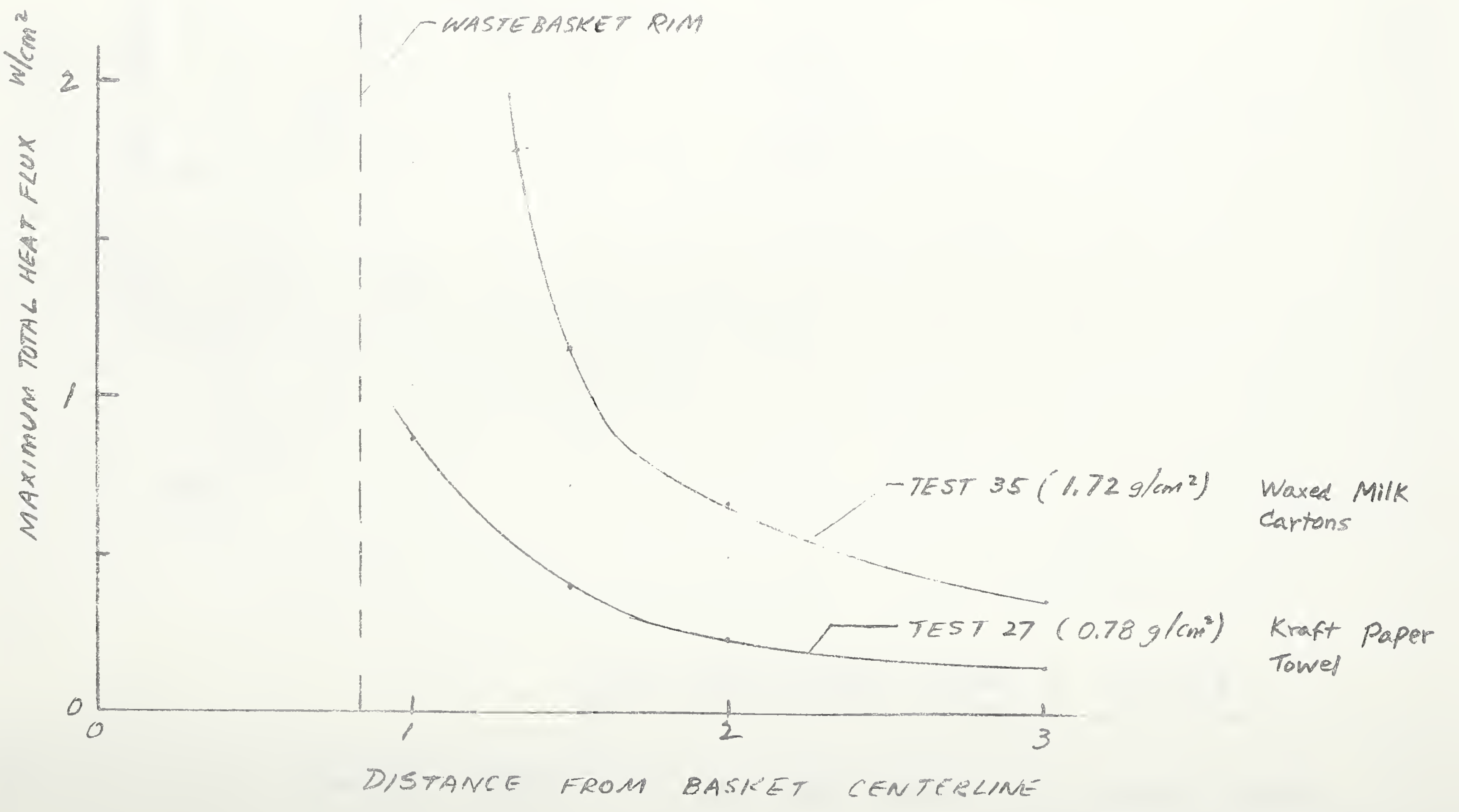


Fig. 8 DISTRIBUTION OF FLUX NEAR A LARGE BURNING WASTEBASKET



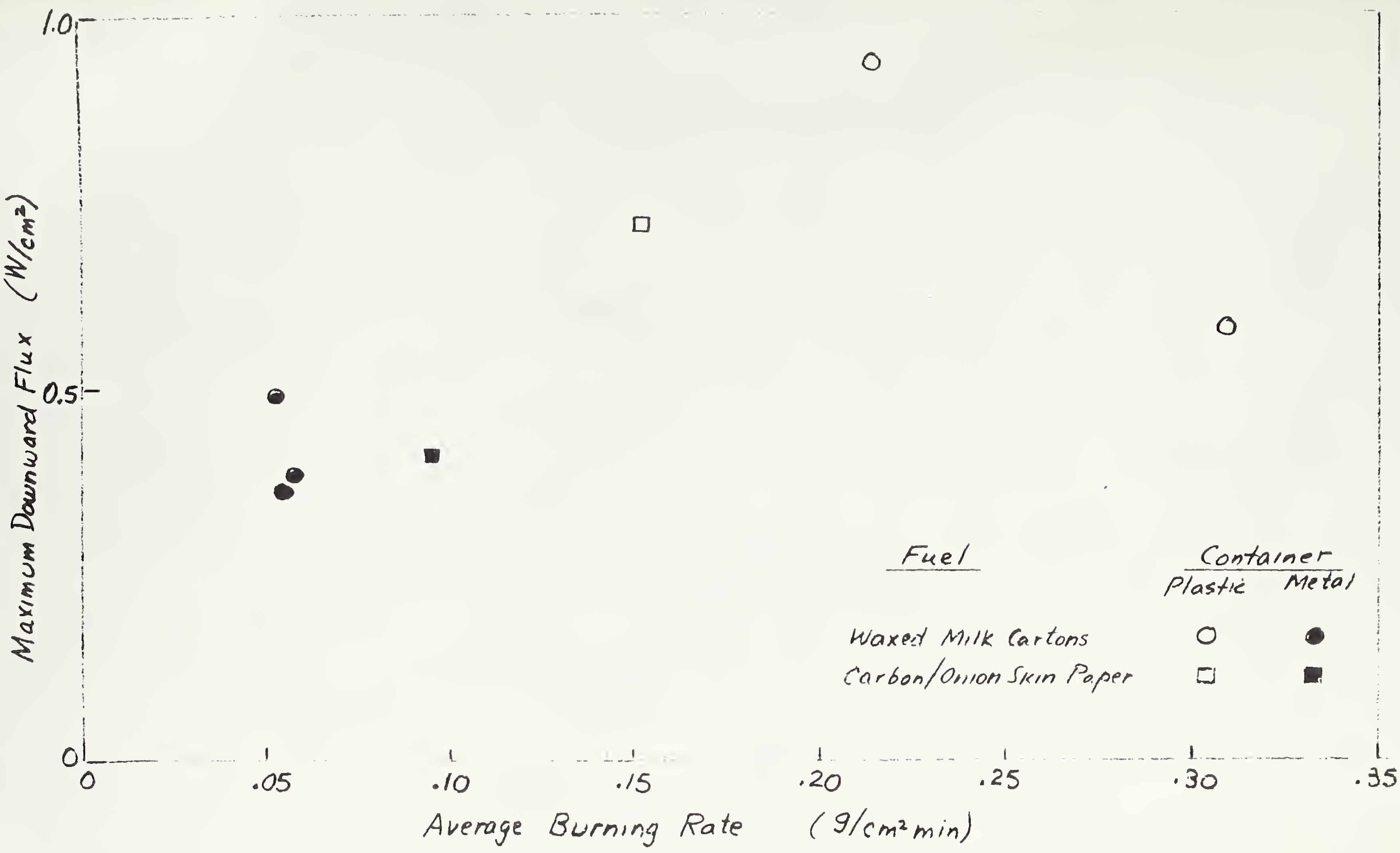


Figure 9 Effect of Type of Container on Maximum Downward Heat Flux and Fuel Burning Rate

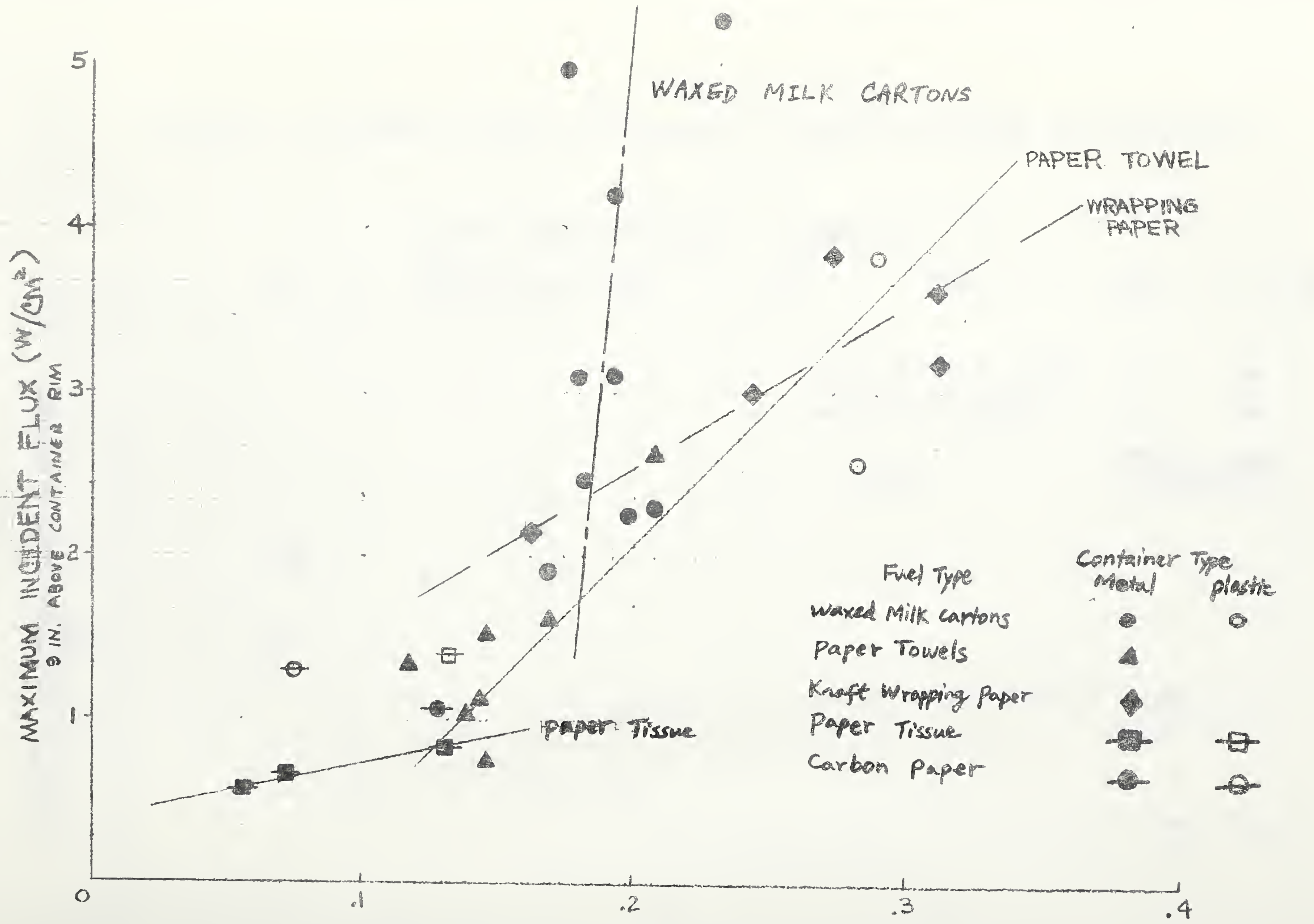


Figure 10 Relationship between Fuel Burning Rate and Maximum Total Flux from the Flame